Phosphorus Site-Specific Criteria Proposal for: Lac Courte Oreilles

AU ID: 15368

WBIC: 2390800

Sawyer County, Wisconsin

June 18, 2014

COLA

LAC COURTE OREILLES

Pride of the Ojibwe

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7300 Hudson Blvd.
Suite 295
Oakdale, MN 55128
651.330.6038
www.limno.com

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Requestor:

The Courte Oreilles Lake Association (COLA)

612-839-8558
garylindapulford@charter.net
15790 West Victory Heights Circle
Stone Lake, WI 54876

In association with:

The Lac Courte Oreille Band of Lake Superior Chippewa Indians

715-634-0102
ddtyrolt@cheqnet.net
LCO Conservation Department
13394W Trepania Rd. Bldg. 1
Hayward, WI 54843

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Prepared by:

LimnoTech, Inc.

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1 Site-Specific Criteria Proposal Overview

This document defines phosphorus site-specific criteria (SSC) for Lac Courte Oreilles (LCO) located in Sawyer County, Wisconsin (WBIC 2390800). The SSC criteria are based on identified lost or threatened designated uses; water quality required for full attainment of these uses; and implementation of antidegradation policies for LCO.

The Lac Courte Oreille Band of Lake Superior Chippewa Indians, in association with the Courte Oreilles Lakes Association (COLA), is proposing SSC for LCO, based on consideration of these factors:

- Rare designation of LCO as an outstanding resource water (ORW);
- Existing impairments to warm-water fish populations (muskellunge) that have occurred since 1976;
- Increasing threats to most sensitive uses or cold-water fish species in the lake (cisco and whitefish);
- Loss of beneficial uses, including boating, fishing, and swimming in Musky Bay, the southwestern lobe of LCO;
- Water quality impairment for total phosphorus in Musky Bay and degradation of Stuckey Bay;
- Documented negative collective influence of Musky and Stuckey Bays on the water quality of LCO's West basin and subsequent downgradient basins and bays;
- Impacted biologic condition based on hypolimnetic dissolved oxygen (DO) levels below 6 μg/L in most of the major bays and basins of LCO;
- Expected impacts of climate change; and,
- The cumulative effects of the above considerations leading to continued degradation and further loss of beneficial uses of this rare designated outstanding resource water without additional protective standards.

The proposed total phosphorus SSC for LCO, to be applied to LCO in its entirety, is 10 μg/L. This is more protective than the current water quality criterion of 15 μg/L.

1.1 Potentially Interested Parties

Parties anticipated to be interested in this phosphorus SSC proposal for LCO include: the Lac Courte Oreilles Band of Lake Superior Chippewa Indians; COLA members; local cranberry bog owners; Great Lakes Indian Fish and Wildlife Commission (GLIFWC); lake and watershed residents; visitors to the lake for recreational activities; the Hayward Chamber of Commerce; local resorts; and the full spectrum of regional businesses and services (grocery stores, trades, home and recreation industry services, recreational fishing guides and outfitters). LCO is central to Tribal culture. It is also central to the region's economy with real estate valued at over $332 million, annual property taxes of $2.9 million, supporting of local infrastructure, plus associated expenditures from residents and vacationers estimated to be about $9.8 million to $14.8 million per year (Wilson, 2008).

1.2 Downstream Waterbodies

Because the proposed SSC for LCO is more protective than the current applicable water quality criterion, a benefit to downstream waterbodies is expected. Waterbodies downstream of LCO include: Little Lac Courte Oreilles (WBIC 2390500), Billy Boy Flowage (WBIC 2389700), Couderay River (WBIC 2384700), and Grimh Flowage (WBIC 2385100). Downstream of the Grimh Flowage, the Couderay River flows into the Chippewa River (WBIC 2050000), which forms Lake Wissota near Chippewa Falls. A Total Maximum Daily Load (TMDL) for phosphorus exists for Little Lake Wissota, which is an embayment of Lake Wissota (WBIC 2152800). Further downstream the Chippewa River flows into Lake Pepin (WBIC 731800). Minnesota Pollution Control Agency is preparing a phosphorus TMDL for Lake Pepin but it has not been finalized. Improved water quality in LCO is not expected to significantly impact either TMDL.

2
Description of Lac Courte Oreilles

This section describes the location, drainage areas, and physical characteristics of LCO, which is located in Sawyer County, Wisconsin (Figure 1).

The lake has a total surface area of approximately 5,039 acres, with approximately 25 miles of shoreline. The maximum depth of LCO is 90 feet, its mean depth is 34 feet, and approximately 28% of the lake is less than 20 feet deep. Following commonly accepted limnological practice and terminology, the three bays (Musky, Stuckey, and Northeast) and three basins (West, Central, and East) comprise one lake referred to as Lac Courte Oreilles (Figure 2), which is identified by one lake identification number (Id# 2390800) and one common lake map http://dnr.wi.gov/lakes/maps/DNR/2390800a.pdf . All of the bays and basins are inter-connected and share one water level (relative to sea level except for short-term variations caused by wind, seiche, storm inflows, etc.). Musky, Stuckey and Northeast bays are not physically distinct upland lake basins connected to LCO by a predominant unidirectional streamflow or outlet structure. These bays share expanses of open water and hence, directly influence each other via advective and dispersive mixing. The distances of open water between each bay and basin are given in Table 1.

Table 1. Distances of open water between each LCO bay and basin.

Bay/Basin Interface	Length of Interface (ft)
Musky Bay/West Basin	1,980
Stuckey Bay/West Basin	770
Central Basin/West Basin	3,150
Central Basin/East Basin	2,565
East Basin/Northeast Bay	1,050

The total drainage area to LCO is 68,990 acres (99.5 square miles). Three tributaries drain 80% the watershed: Grindstone, Osprey, and Whitefish Creeks (Figure 2). Land cover/ use in the watershed is predominantly forested (53%) with the remainder being water (31%), grassland (8%), residential (4%), agriculture (4%), and commercial (0.1%) (Wilson, 2011). Five cranberry bogs are located within the drainage areas of Musky Bay, Stuckey Bay, West Basin, and East Basin (Figure 2).

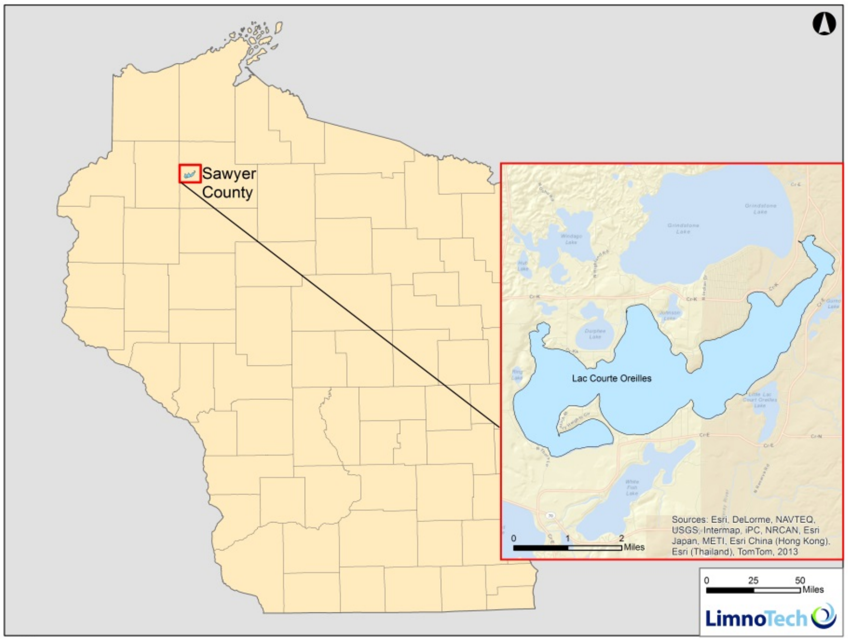

Figure 1. Location of LCO within Wisconsin.

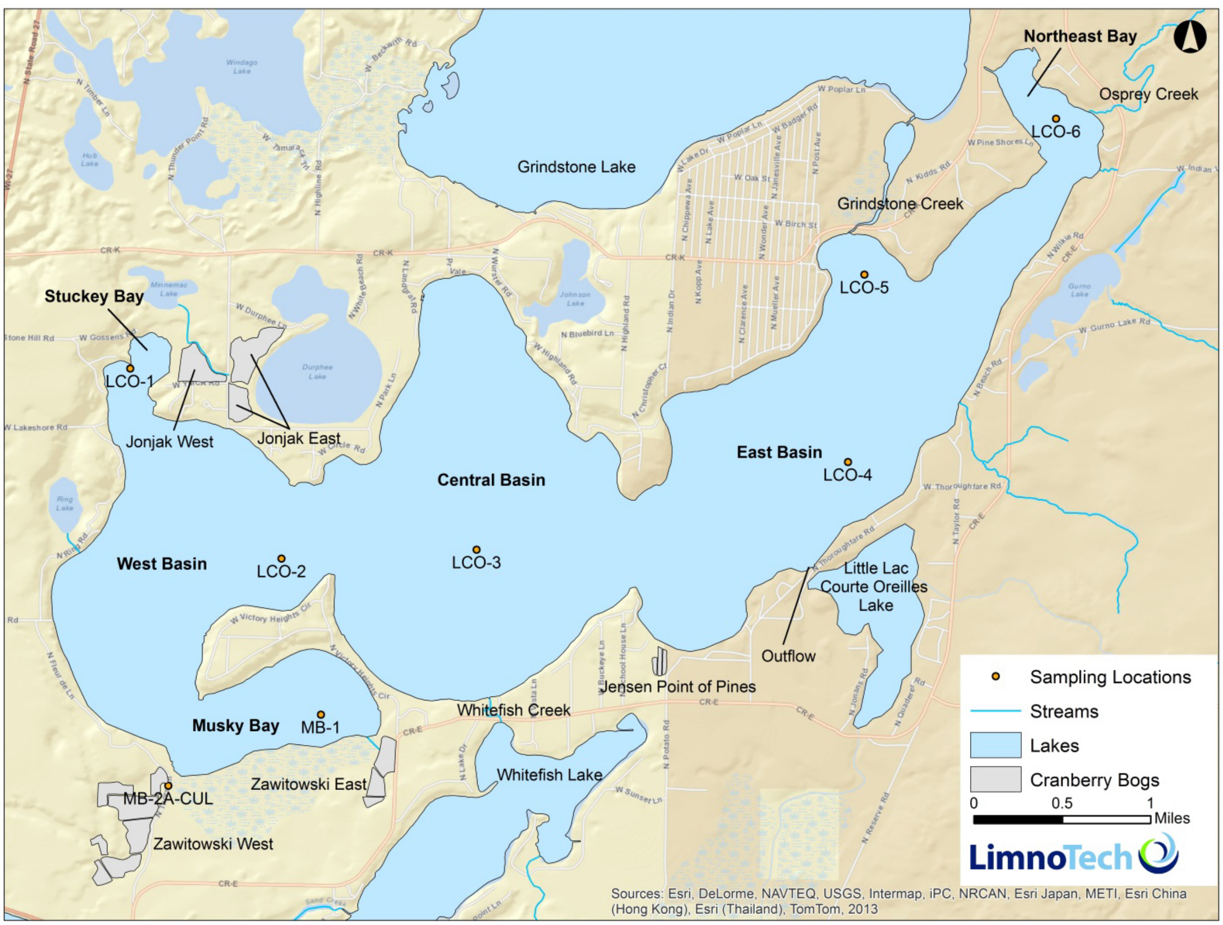

Figure 2. LCO map showing tributaries, major basins and bays, sampling stations, and cranberry bog locations.

3
Significance to Lac Courte Oreilles Band

> *"Water, as it flows the rivers, lakes and streams, seeps underground passageways, or spurts out of the Earth's surface as an artesian well – the Earth's water system is compared to the human circulatory system in Ojibwe thought. So, the wellbeing of water, which affects every other living part of the Earth, is of vital importance to the Ojibwe people and to all people. Water, known as nibi in Ojibwemowin, is the source of life and, as such, becomes the responsibility of women. Nibi must be protected, kept pure, for all life now and to come."*[1]

The 7,600 member Lac Courte Oreille Band of Lake Superior Chippewa Indians consists of a land base of 76,500 acres in northwest Wisconsin. The Lac Courte Oreilles Reservation, like much of northern Wisconsin, contains tremendous water resources. Numerous rivers, streams, lakes, ponds, and wetlands, as well as groundwater, make up the water resources landscape of the Reservation. In fact, nearly 20% of the total reservation area, or just over 15,000 acres of surface waters make the LCO reservation a "water rich" environment. All of these waters are located entirely within the Upper Chippewa River Basin. More than forty-three miles of rivers and streams, as well as all or portions of 26 named lakes can be found on the reservation. Additionally, over 7,500 acres of the reservation territory are classified as wetlands.

These water resources have provided subsistence, cultural, and spiritual benefits to many generations of Lac Courte Oreilles Ojibwe. The lakes of the reservation and the surrounding ceded territories, which includes Lac Courte Oreilles lake, contribute to Sawyer County's status as one of the premier tourist areas in Wisconsin.

One-third of Lac Courte Oreilles lake is located within reservation boundaries, with the rest of the lake located within the ceded territory. Water quality degradation resulting from excessive levels of phosphorus in any portion of Lac Courte Oreilles Lake impacts the waters within the reservation boundaries due to mixing occurring between the various bays and basins.

The Lac Courte Oreilles Tribal Conservation Department (LCOCD) has been monitoring LCO since 1996 with routine monitoring beginning in 2002. The majority of the data presented in this document were collected by or in partnership with LCOCD.

[1] Integrated Resource Management Plan 2010 Lac Courte Oreilles Band of Lake Superior Ojibwe, pg. 25. Quoting: Seasons of the Ojibwe, 2002 Edition, Published by the Great Lakes Indian Fish and Wildlife Commission.

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4 Outstanding Resource Water Designation and Current Applicable Water Quality Criteria

This section describes the current classifications of LCO and the water quality criteria currently applied to the lake.

4.1 Outstanding Resource Water (ORW) Classification

Lac Courte Oreilles is classified as an outstanding resource water (ORW) by Wisconsin Department of Natural Resources (WDNR). The lake was first listed as such in Wisconsin Administrative Code (WAC) NR 102.10 in 1993 (WAC, 1993).

Fewer than 1% of Wisconsin's lakes are designated as ORWs. Wisconsin's antidegradation rule (WAC NR 207) protects ORWs by only allowing new or expanded discharges if current water quality is maintained:

> *"If the department determines that a WPDES permit application proposes a new or increased discharge to outstanding resource waters, effluent limitations for substances in the new or increased portion of the discharge will be set equal to the background levels of these substances, upstream of, or adjacent to, the discharge site unless it is determined that for Great Lakes system waters, such limitations would result in significant lowering of water quality under s. NR 207.05 (4) (b). Effluent limitations for those substances shall be determined in accordance with s. NR 207.04."*

4.2 Total Phosphorus Criteria

LCO has been designated as a deep (stratified) two-story cold-water fishery lake for purposes of applying water quality criteria for phosphorus. The WDNR's most protective total phosphorus criterion, 15 µg/L, has been applied to LCO (WAC NR 102.06).

WDNR has considered Musky Bay a separate, physically distinct, upland lake and characterized it as a shallow (non-stratified) drainage lake using the partial lakes assessment in the 2012 Wisconsin Consolidated Assessment and Listing Methodology (WisCALM; WDNR, 2012). The WDNR also determined that the applicable total phosphorus criterion for this class of lakes is 40 µg/L (WAC NR 102.06). Musky Bay was included on Wisconsin's 303(d) list in 2012 as impaired for total phosphorus.

Musky Bay, Stuckey Bay, and Northeast Bay are not physically separate upland lakes draining into LCO via streams or outlet structures. From a statewide policy consistency perspective, assigning separate upland lake standards to Musky Bay would suggest assignment of the same standards to Stuckey Bay and Northeast Bay, which would clearly violate antidegradation provisions of state and federal water rules. Musky Bay's water quality has been degraded and designated beneficial uses have been lost or threatened since passage of the federal Clean Water Act.

4.3 Dissolved Oxygen Criteria

For cold-waters in Wisconsin, dissolved oxygen may not be artificially lowered to less than 6.0 mg/L at any time or to less than 7.0 mg/L during spawning season (WAC NR102.04).

5 Fishery Impairment and Threats

LCO supports both warm-water and cold-water fish species. Of the warm-water species, muskellunge have been a highly sought after fish in LCO. Cold water species in LCO include cisco and whitefish. Populations of muskellunge are impaired in LCO, while whitefish and cisco populations are threatened.

Interaction occurs between the warm-water and cold-water fisheries; cold-water species are a key forage species for trophy gamefish. LCO produces world record muskellunge and large walleye, smallmouth, and northern, due to the presence of cisco and whitefish as food sources. Without the cold-water species, gamefish would be smaller, if not less abundant. The angling public would view this as a significant impairment (Pratt and Neuswanger, 2006).

5.1 Muskellunge

The report "Loss of Beneficial Uses, Musky Bay, Lac Courte Oreilles" (Pratt, 2013) presents data, analysis, and documentation of biological impacts in Musky Bay caused by elevated phosphorus discharges into the bay and internal phosphorus cycling in the bay. The documented impairments include: 1) depleted oxygen levels (discussed further in Section 7.2); 2) fish kills; 3) loss of muskellunge spawning habitat; 4) excessive macrophyte growth; and 5) loss of native macrophyte species as a result of curly leaf pondweed infestation (curly leaf pondweed impacts are discussed in Section 6).

Muskellunge, once present in large numbers predominantly in Musky Bay, are no longer reproducing in Musky Bay. No successful spawning has been documented in the bay since 1970 (Johnson, 1986). The cause of muskellunge decline was once thought to be competition with northern pike. However, removal of 60% of northern pike from Musky Bay in 2007 did not result in muskellunge reproduction (Pratt, 2007). Research on fish DNA in LCO showed a sustained genetic signature that would not exist if recruitment was entirely due to stocking; therefore natural reproduction of muskellunge must occur within LCO at locations other than Musky Bay (Sloss, 2006; Sloss et al. 2008; AFS 2003).

The evidence now points to oxygen depletion in Musky Bay, which occurs both during spawning season and during ice cover, as the cause of muskellunge decline. Dissolved oxygen depletion in Musky Bay is caused by two primary factors: 1) excessive inputs of phosphorus and 2) die-off of curly leaf pond weed (see Section 6).

The strain of muskellunge in LCO deposit their eggs at the bottom of the lake on the sediment surface (Pratt and Neuswanger, 2006). The eggs require 2 mg/L of dissolved oxygen to survive (Pratt, 2013). It is thought egg survival is hindered by the highly flocculent sediments present at the sediment surface in Musky Bay; the eggs sink into the flocculent layer, where very low or little oxygen exists, and die.

Other life stages of muskellunge are also impacted by low dissolved oxygen in the bay. Dissolved oxygen levels below 3 mg/L in lake bottom waters in the summer and in the water column in winter are known to cause stress and movement of muskellunge out of the low oxygen region (Pratt, 2013). With dissolved oxygen concentrations below 1 mg/L, all fish are severely stressed and some will die. At 0.5 mg/L dissolved oxygen, all fish will likely die. Dissolved oxygen conditions in Musky Bay are discussed in Section 7.2.

Winterkill data from WDNR's Hayward fisheries files indicates that Musky Bay accounts for two-thirds of the recorded fish kills in Sawyer County since 1996 (Pratt, 2013). Overall, there has been a decline in winterkills in Sawyer County from the 1960-1979 and 2000-2012 time periods from 35 to three. The trend in winterkills in Musky Bay is opposite of the countywide trend, with no winterkills between 1960-2002 and two winterkills in the 2003-2012 period.

5.2 Cisco and Whitefish

The most sensitive uses include cold-water fisheries, which are reliant on sufficient dissolved oxygen concentrations in the cooler bottom waters of a lake. Increased nutrient loading to a lake can result in a reduction of oxygen in the hypolimnion, as is seen in LCO (see Section 7.2). Die-offs of cold-water species may occur as these populations are driven into warmer surface waters.

LCO is considered to be among the three lakes with the best cold water fisheries that were surveyed for WDNR's 2012-13 two-story lake study (Kampa, personal communication, January 2014), which was focused on lakes in northwestern Wisconsin. The other top two lakes surveyed in this period are Grindstone and Whitefish Lakes, both of which drain into LCO. However, WDNR survey information indicates that both whitefish and cisco populations are threatened in LCO (Pratt, 2013). Only two whitefish were found in the survey (both in Whitefish lake).

Cisco populations are faring relatively well; however, there is evidence that cisco habitat is being compressed by lower dissolved oxygen levels and increased temperatures. In all three lakes, dissolved oxygen levels measured in the bottom waters are lower than the levels cisco are reported to prefer or able to withstand (Table 2).

Table 2. Summary of WDNR 2012-2013 "two-story lake" surveys.

Lake	Survey Date	Sets	No. Cisco (CPE)	No. Whitefish (CPE)	Water Depth (ft)	Temp. (°F)	DO (mg/L)
LCO	7-16-13	3	28 (9.3)	0	22-75	44-55	2.8-8.0
Whitefish	8/06-8/09-12	4	218 (5.5)	2 (0.5)	35-83	44-49	1.6-6.3
Grindstone	8-28-13	1	25 (25.0)	0	28-40	49-68	1.0-5.8

CPE= catch per effort

Summary of data from Jeff Kampa (Personal communication, January, 2014).

Whitefish, the presence of which is much rarer in general than cisco, are far more sensitive to dissolved oxygen levels than cisco. Whitefish prefer lower temperatures than cisco and therefore have an affinity to bottom waters. Their preferred summer habitat is approximately 10% or less by volume of cisco habitat (Pratt, personal communication, May 2014). LCO and Whitefish Lake are the only two known lakes in Wisconsin to date that don't contain lake trout but do contain both cisco and whitefish.

6
Loss of Recreational Designated Use

LCO draws thousands of visitors each year from Wisconsin, Minnesota, Illinois, and other states (Wilson, 2010). Approximately 20,000 fishing trips are conducted at LCO annually, with approximately 12% (2400 trips) conducted in Musky Bay. The total minimum value of these trips is estimated at $700,000 per year, with $75,000 per year in Musky Bay (Pratt and Neuswanger, 2006). However, recreational use of Musky Bay is impaired due to excessive aquatic plant growth and by the aquatic invasive species curly leaf pondweed, as well as by the presence of dense algal mats.

Curly leaf pondweed, first identified in the lake in 2005, is now established throughout Musky Bay. Its presence hinders or completely impairs recreational use of this portion of LCO for much of the year. Annual fish surveys have been conducted in the fall by WDNR and Great Lakes Indian Fish and Wildlife Commission (GLIFWC). Notes from the field surveys indicate whether navigation of Musky Bay was possible in the boom-shocker boat used in fisheries assessments, and therefore serve as a measure of fishing, boating, and swimming accessibility of Musky Bay.

The WDNR and GLIFWC survey notes document two levels of impairment to a successful fish survey: 1) survey made harder and less effective; and 2) survey cancelled or not completed. Since the surveys were conducted in the fall and not during the height of the growing season, they underestimate the level of impairment to navigation. Based on the fish survey field notes from 1992 to 2008, surveys at Musky Bay were completed with some difficulty in 1992, 1996, 1997. In 1998, 2003, and 2008, surveys were not able to be completed (field notes for these years were: "heavy weeds", "not navigable", and "motor fouling"). The Musky Bay station was permanently discontinued from the survey program in 2009 (Pratt, 2013).

While curly leaf pondweed has not been recognized as a biological impairment previously (e.g. 2012 WisCALM; WDNR, 2012), its presence contributes to impairment of LCO, including affecting native aquatic plant species and contributing to lowering of dissolved oxygen and increased nutrient levels during die off, which occurs in mid-summer (UW Extension, 2013).

COLA and WDNR have spent approximately $40,000 per year on curly leaf pondweed control since 2010 in an effort to mitigate the phosphorus release/algal bloom and dissolved oxygen slump associated with curly leaf pondweed die off and to facilitate navigation in Musky Bay. Aquatic plant surveys were conducted in Musky Bay in 2007 and then in 2011 to assess the effectiveness of curly leaf pondweed control. Between 2007 and 2011, 48% of native species declined, 14% disappeared, and 65% remained stable in the bay (Stantec, 2012).

Algal mats, which are likely a manifestation of the excess phosphorus concentrations in Musky Bay, also periodically limit swimming, boating, and fishing in the bay (Figure 3).

Figure 3. Algal mats in Musky Bay in September, 1999. (Source: USGS, 2003. Photo by Paul Garrison, WDNR.)

7 Water Quality

In 2008 and 2010, COLA petitioned WDNR to list Musky Bay as an impaired water. Concern exists over water quality and biological conditions in Musky Bay as well as the influence of water quality in Musky Bay on conditions in LCO as a whole. The current 15 µg/L total phosphorus criterion that applies to LCO is not protective of LCO's designated beneficial uses, as evidenced by hypolimnetic dissolved oxygen conditions threatening cold water fish species as described in Section 5 and below in Section 7.2.

This section presents a summary of water quality conditions in LCO based on quality assured monitoring data collected by LCOCD. Data presented here span the 2002 to 2013 time period. Monitoring stations are indicated on Figure 2.

The focus of the presented data is on defining biological endpoints in LCO as defined for deep (stratified) lakes in WDNR's draft Site-Specific Criteria Framework for Wisconsin (2014a). The applicable thresholds are:

- Chlorophyll *a* does not exceed 20 µg/L for more than 5% of days during the summer (6 days), as calculated using 2012 WisCALM (WDNR, 2012) guidance[2].
- Macrophytes do not indicate an impairment. Note: specific metrics for assessment of this condition are under development.
- Dissolved oxygen in two-story fishery lakes, such as LCO, must meet the above thresholds for chlorophyll *a* and macrophytes, and must also have dissolved oxygen >6 mg/L in the hypolimnion.

Total phosphorus, chlorophyll *a*, macrophyte, and dissolved oxygen conditions in LCO are presented below. In addition, temperature conditions in Musky Bay are presented that demonstrate the bay's intermittently stratified nature.

7.1 Analysis of Total Phosphorus

This section presents an analysis of current ambient total phosphorus conditions in LCO and historical total phosphorus conditions based on sediment cores.

7.1.1 Current Ambient Conditions

Epilimnetic total phosphorus data for seven LCO sampling stations (LCO 1 thru 6 and MB1; Figure 2) were analyzed according to the assessment protocols for fish and aquatic life uses described in 2014 WisCALM (WDNR, 2013) for the June 1 to September 15 season. While data are available dating back to 2002, the most recent five-year period for each station was chosen, except where additional qualifying years were necessary to total five years. Therefore, data used in the analysis span the time period of 2007 to 2013. The impairment analysis was conducted for each major basin and bay in LCO. The results of the

[2] Note: Data presented in this proposal were assessed using protocols established in 2014 WisCALM (WDNR, 2013).

assessment, including the "grand mean" for each basin and bay, the associated confidence interval, and the resulting assessment category are given in Table 3, along with the criteria thresholds and appropriate impairment "decision". The number of monthly means used for each basin and bay and the associated monitoring time periods are also given in the table.

Table 3. Total phosphorus condition assessment for fish and aquatic life uses by LCO basin and bay.

Bay/Basin	Musky Bay	Stuckey Bay	West Basin	Central Basin	East Basin	Northeast Bay
Total no. daily averages	81	46	38	38	92	38
No. months in grand mean	28	19	17	16	24	17
Period of record	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013
No. years used	7	6	6	6	7	6
Grand Mean	**35.4**	**18.1**	**14.7**	**11.0**	**11.6**	**11.8**
Lower 90% Confidence Interval	33.3	11.8	10.1	8.6	10.5	10.1
Upper 90% Confidence Interval	37.6	24.3	19.2	13.4	12.7	13.5
Recreational Use (REC) Threshold	15	15	15	15	15	15
Fish and Aquatic Life Use (FAL) Threshold	15	15	15	15	15	15
REC Assessment	**Clearly exceeds**	**May exceed**	**May meet**	**Clearly meets**	**Clearly meets**	**Clearly meets**
FAL Assessment	**Clearly exceeds**	**May exceed**	**May meet**	**Clearly meets**	**Clearly meets**	**Clearly meets**

Based on the assessment, total phosphorus concentrations are highest in Musky Bay, indicating both recreational and fish and aquatic life use impairments when compared to the 15 µg/L threshold for two-story fishery, deep drainage lakes. In Stuckey Bay and West Basin (Figure 2), total phosphorus concentrations are of potential concern for both fish and aquatic life uses and recreational use. Central Basin, East Basin, and Northeast Bay are meeting total phosphorus mean concentration criteria.

Despite the majority of LCO meeting current total phosphorus criteria, LCO has an impaired biologic condition evidenced by low dissolved oxygen (<6 mg/L) in the hypolimnion as discussed in Section 7.2. This indicates that LCO is more sensitive to total phosphorus inputs than average lakes of its kind. This possibility is recognized by WDNR in their 2014 draft Site-Specific Criteria Framework for Wisconsin, which states "…waterbodies may be more sensitive to phosphorus and experience biological responses and use impairments at lower levels than usually expected."

Mean annual and seasonal total phosphorus concentrations for the 2002 to 2013 period are provided for the major LCO basins and bays in Figure 4.

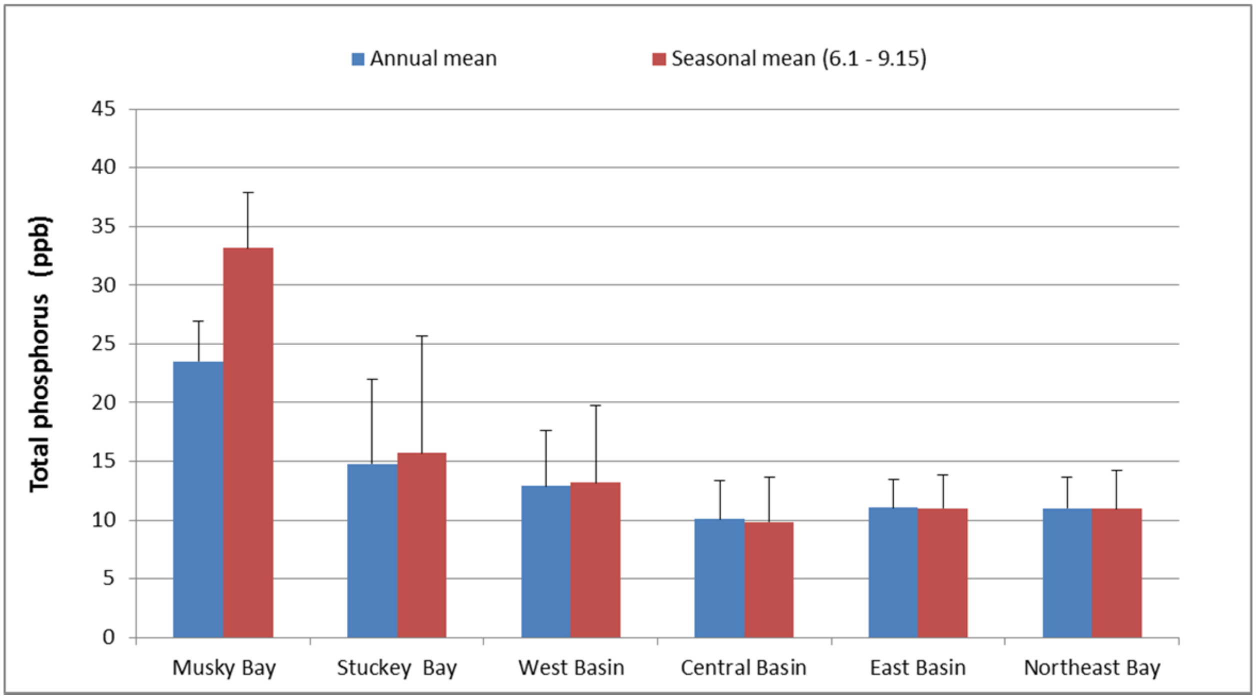

Figure 4. Annual mean and seasonal mean total phosphorus (June 1-Sept 15) in major bays and basins of LCO (2002-2013). Errors bars indicate ±1 SD.

7.1.2 Historical Conditions

Historical water quality patterns in LCO were examined by USGS based on analyses of sediment cores collected in 1999 and 2001 (Fitzgerald et al, 2003). Cores were collected in Musky Bay (five locations), Northeastern Bay (two locations), Stuckey Bay, and the center of the lake (deep hole). Samples from the cores were analyzed for minor and trace elements, nutrients, biogenic silica, diatoms, pollen, and radioisotopes.

The cores from one of the Musky Bay sites in the study (MB-1) indicated that since the 1980's, phosphorus levels increased dramatically in the bay while iron levels decreased almost as dramatically (from approximately 7:1 to approximately 1:1). The lower phosphorus to iron ratios indicate a likelihood of internal phosphorus release (USGS, 2003). Study results indicated that the histories of several elements in Musky Bay, including phosphorus, were confounded by organic-matter decomposition and chemical redistribution (possibly by macrophytes) after deposition, thus limiting their use for reconstructing historic nutrient inputs. Dating of the cores from Northeastern Bay was not possible due to disturbances that happened after deposition as indicated in the radioisotope profiles. Total phosphorus core profiles for Musky Bay and Northeastern Bay from the USGS (2003) study are shown in Figure 5.

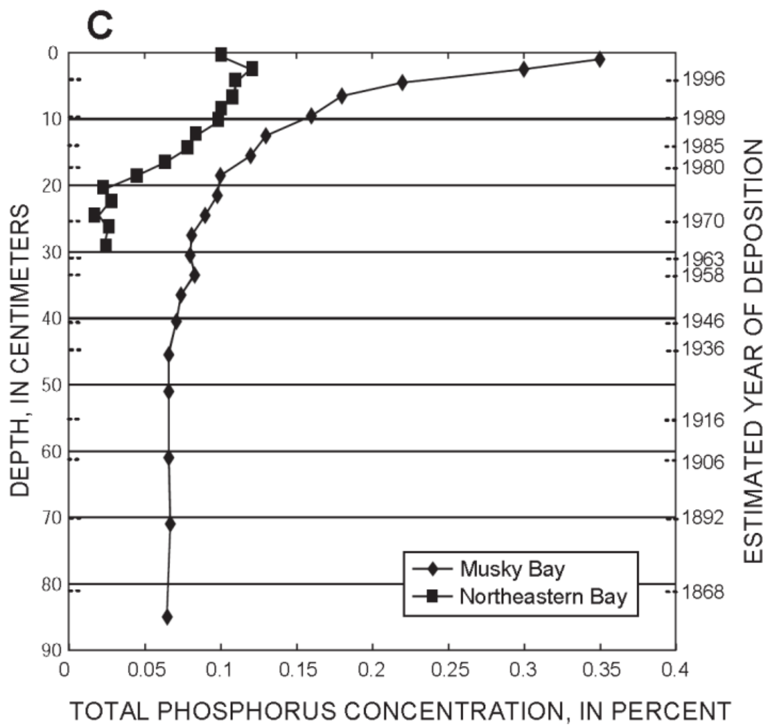

Figure 5. Total phosphorus concentrations in sediments of Musky Bay and Northeastern Bay, LCO with estimated date of deposition for the Musky Bay profile only. (Source: Figure 11; USGS, 2003).

Evaluation of the silica, diatom, and pollen data from the Musky Bay sediment cores indicated an increased growth of aquatic plants during the 25 years preceding the study and establishment of floating algal mats in the preceding decade. Increased nutrient inputs to Musky Bay were indicated after approximately 1940 and also in the 1990s by several lines of evidence (USGS, 2003).

WDNR's draft guidance for site-specific criteria (WDNR, 2014) requires the use of a sediment core to establish historical water column total phosphorus concentrations in cases where total phosphorus concentrations are not exceeding statewide criteria but the biology is impaired and a more stringent SSC is sought. The guidance specifies that the core is to be collected from the deepest part of the lake.

Paul Garrison at WDNR was contacted regarding the possibility of discerning a pre-development total phosphorus concentration for LCO based on the deep hole sediment core collected for the USGS study. Based on this request, diatoms in both the top and bottom sample from the top/bottom core collected at the deep hole location were re-counted and the results run through a weighted average model for deep lakes (Birks, et al., 1990). A concentration of 10 µg/L was predicted in the top sample. The model was not able to accurately predict total phosphorus concentrations in the deep hole bottom sample due to limitations in the model (Garrison, 2014). Collection of new samples would not improve the ability to predict pre-development total phosphorus concentrations (Garrison, personal communication, May 2014).

7.2 Verification of Biologic Condition

LCO's biologic condition was assessed based on its classification as a deep lake and a two-story fishery. Chlorophyll *a*, macrophytes, and dissolved oxygen conditions in the lake are described below.

7.2.1 Chlorophyll *a*

As with the total phosphorus analysis described in Section 7.1, epilimnetic chlorophyll *a* data for seven LCO sampling stations (LCO 1 thru 6 and MB1; Figure 2) was analyzed according to the assessment protocols for fish and aquatic life uses described in 2014 WisCALM (WDNR, 2013) for the July 15 to September 15 season. Data were not analyzed for recreational use impairments since chlorophyll *a* concentrations in LCO are generally below impairment levels; only five out of 201 total chlorophyll *a* samples had concentrations greater than 20 µg/L, all of which were located in Musky Bay.

While data are available dating back to 2002, the most recent five-year period for each station was chosen, except where additional qualifying years were necessary to total five years. Therefore, data used in the analysis span the time period of 2007 to 2013. The impairment analysis was conducted for each major basin and bay in LCO. The results of the assessment, including the "grand mean" for each basin and bay, the associated confidence interval, and the resulting assessment category are given in Table 4, along with the criteria thresholds and appropriate impairment "decision". The number of monthly means used for each basin and bay and the associated monitoring time periods are also given in the table. Based on the assessment, all bays and basins except Musky Bay meet fish and aquatic life uses based on chlorophyll *a*.

Table 4. Chlorophyll *a* condition assessment for fish and aquatic life uses by LCO basin and bay.

Bay/Basin	Musky Bay	Stuckey Bay	West Basin	Central Basin	East Basin	Northeast Bay
Total no. daily averages	46	28	22	22	61	22
No. months in grand mean	20	14	12	11	19	11
Period of record	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013	2007-2013
No. years used	7	6	6	6	7	6
Grand Mean	**9.8**	**2.4**	**2.0**	**1.7**	**2.0**	**2.0**
Lower 90% Confidence Interval	7.9	2.0	1.6	1.5	1.8	1.7
Upper 90% Confidence Interval	11.8	2.7	2.3	1.8	2.2	2.3
Fish and Aquatic Life Use (FAL) Threshold	10	10	10	10	10	10
FAL Assessment	**May meet**	**Clearly meets**	**Clearly meets**	**Clearly meets**	**Clearly meets**	**Clearly meets**

Mean annual and seasonal chlorophyll *a* concentrations for the 2002 to 2013 period are provided for the major LCO basins and bays in Figure 6.

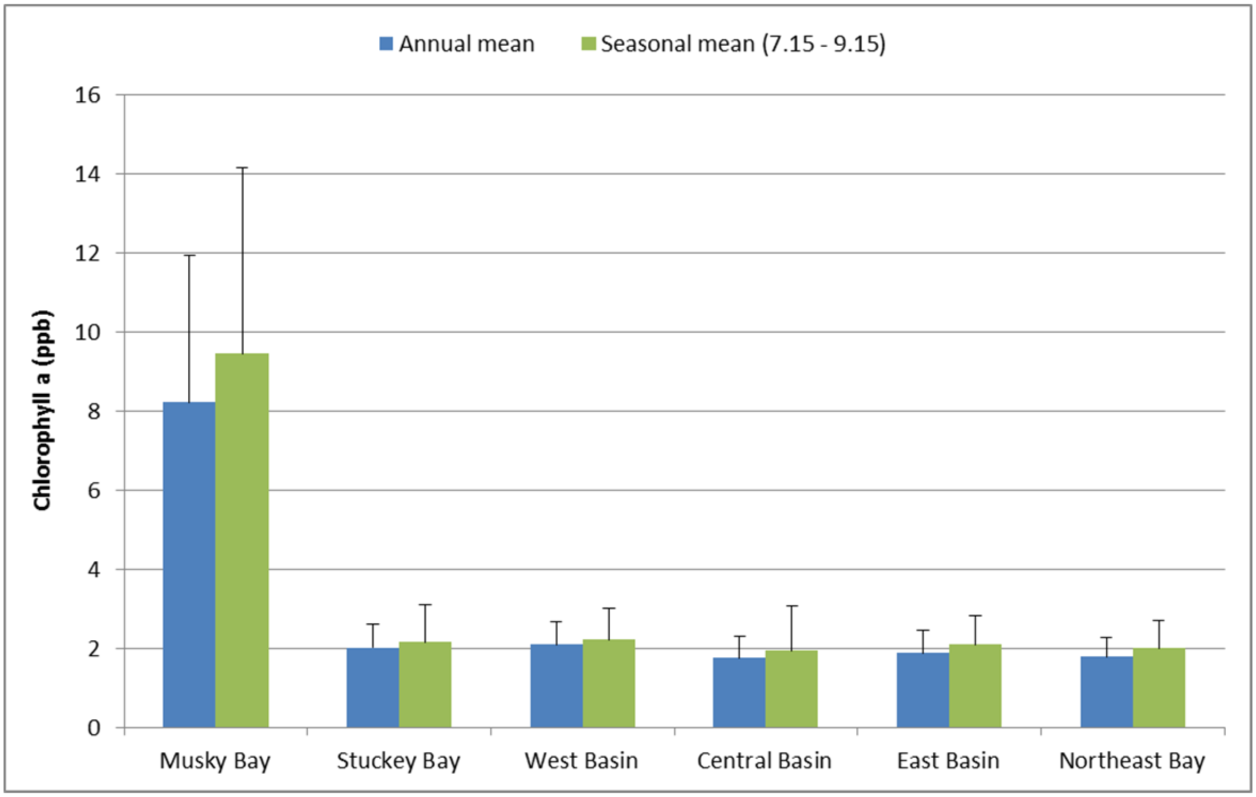

Figure 6. Annual mean and seasonal mean chlorophyll a (July 15- Sept 15) in major basins and bays of LCO (2002-2013). Errors bars indicate ±1 SD.

7.2.2 Macrophytes

Point intercept surveys were conducted in LCO in 2007 (Musky Bay) and 2010 (lakewide) following WDNR protocols. In addition, a visual shoreline survey was completed in June 2010 to look for the presence of invasive species. The results of these surveys are documented in Macrophyte Survey Musky Bay-Lac Courte Oreilles (Harmony, 2007) and Appendix B of the Lac Courte Oreilles Aquatic Plant Management Plan (Tyrolt, 2011).

The 2010 point-intercept survey was conducted in August using a 2,254 point grid generated by WDNR. Based on this survey, LCO has a very diverse plant community with a total of 36 species (35 native and one exotic). Species abundance is balanced between the different types of plants. The Simpson's diversity index of 0.94 calculated based on 2010 study results indicates a healthy ecosystem and a high degree of diversity (Tyrolt, 2011).

The floristic quality index (FQI) calculated for LCO was 36.0 with 33 species used. The mean conservatism value was 6.27. The number of species and FQI are greater than the median values for lakes in the same eco-region (Northern Lakes and Forests), while the mean conservatism value is slightly lower. The high FQI is indicative of a plant community that is healthy, intolerant to development and other human disturbances in the watershed, and has changed little in response to human impact on water quality and habitat changes. This value also indicates a high degree of water quality (Tyrolt, 2011).

Musky Bay has a robust and diverse plant community (Tyrolt, 2011); however, the community structure is being negatively influenced by curly leaf pondweed infestation as described in Section 6. Several other areas of LCO are impacted by curly lead pondweed, including Northeast Bay (Barbertown Bay) and

Stuckey Bay. Grindstone Bay is being watched due to the presence of curly lead pondweed in Little Grindstone Lake, which flows into the bay (Tyrolt, 2011).

7.2.3 Dissolved Oxygen

Dissolved oxygen is a biologic impairment indicator for two-story fishery lakes (WDNR, 2014). A concentration of 6 mg/L must be maintained in the hypolimnion in these lakes to support the cold water fishery.

To assess hypolimnetic dissolved oxygen conditions in LCO, profiles of temperature and dissolved oxygen collected at seven LCO stations (LCO 1 thru 6 and MB1; Figure 2) in 2013 were evaluated. Monitoring was conducted on a total of 19 dates between May 28 and October 17; Not all stations were monitored on each date. Each depth profile was visually inspected to evaluate whether the lake was stratified at the time of monitoring. The lake stratified at all stations, including MB1 in Musky Bay, during the monitoring period. For dates where stratified conditions existed, professional judgment was used to select depths at which measurements were located within the hypolimnion. Hypolimnetic dissolved oxygen measurements were then averaged for each date by station. Stratification conditions in Musky Bay are discussed further in Section 7.3.

Table 5 presents a summary of dissolved oxygen concentrations by major bay and basin, as well as the percent exceedance of the 6 mg/L impairment threshold. Where more than one station was sampled in a basin or bay, daily values were averaged by basin or bay. Mean hypolimnetic dissolved oxygen for the 2013 monitoring period is shown in Figure 7.

Table 5. Summary of hypolimnetic dissolved oxygen in major basins and bays of LCO (June – October 2013).

Bay/Basin	Mean DO (mg/L)	Min DO (mg/L)	Max DO (mg/L)	Count of Daily Means	% Less than 6 mg/L
Musky Bay	3.24	0.85	9.87	11	82%
Stuckey Bay	8.44	6.11	11.24	9	0%
West Basin	2.23	0.04	8.43	19	84%
Central Basin	3.50	0.13	9.78	19	68%
East Basin	5.47	0.04	11.20	32 (two stations)	44%
Northeast Bay	7.99	5.95	11.22	14	7%

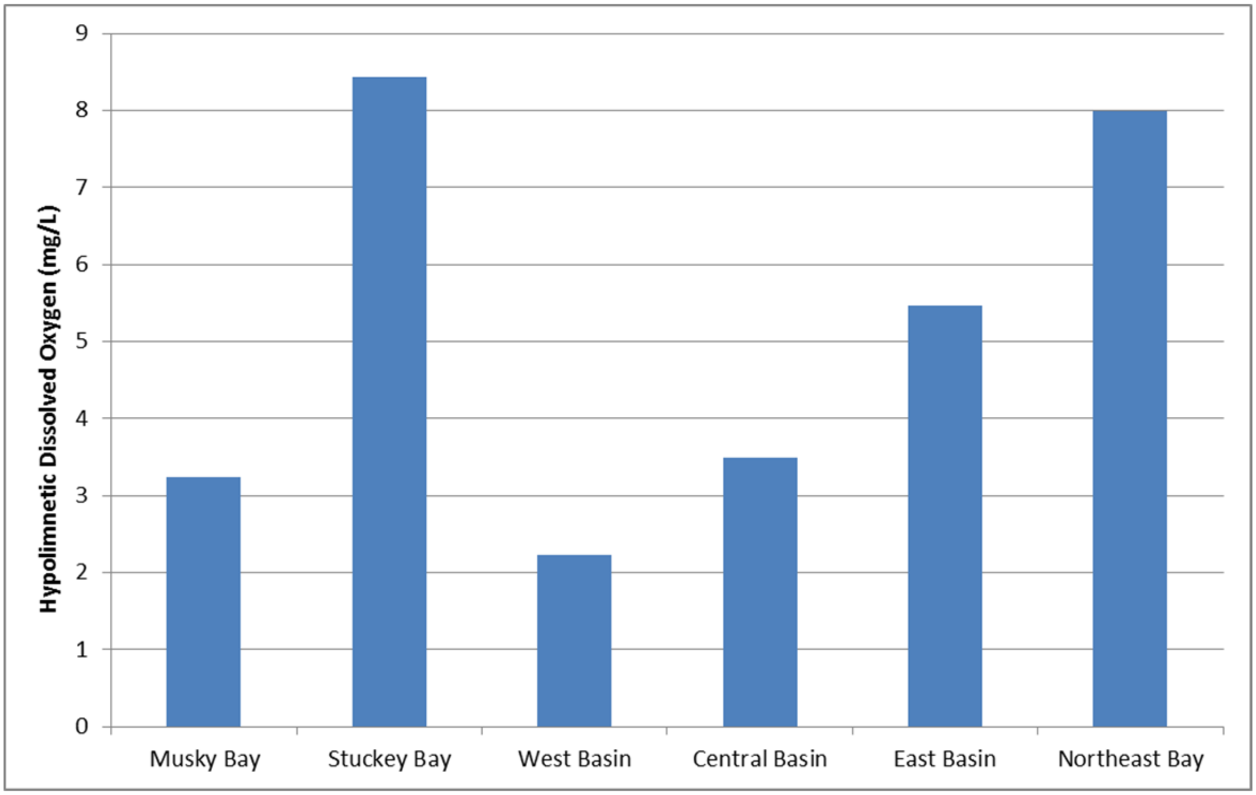

Figure 7. Seasonal mean hydpolimnetic dissolved oxygen in major basins and bays of LCO (June - October 2013).

All basins and bays but Stuckey Bay had at least one daily average hypolimnetic dissolved oxygen concentration below 6 mg/L (Table 5). Means for 2013 were below 6 mg/L in Musky Bay, West Basin, Central Basin, and East Basin. Data was available for more than 10 dates in 2013 for all basins and bays except Stuckey Bay. The percent of monitoring days where average hypolimnetic dissolved oxygen was below 6 mg/L was greater than 10% in all locations except Stuckey Bay and Northeast Bay, with the rest of the percent noncompliance exceedances ranging from 44% to 84%. These results indicate an impairment of the biologic condition of LCO based on its designation as a two-story fishery lake.

Low hypolimnetic dissolved oxygen conditions in Musky Bay are also of a concern for muskellunge reproduction as discussed in Section 5.1. Temperature and dissolved oxygen profiles for 2013 Musky Bay data are presented in Figure 8.

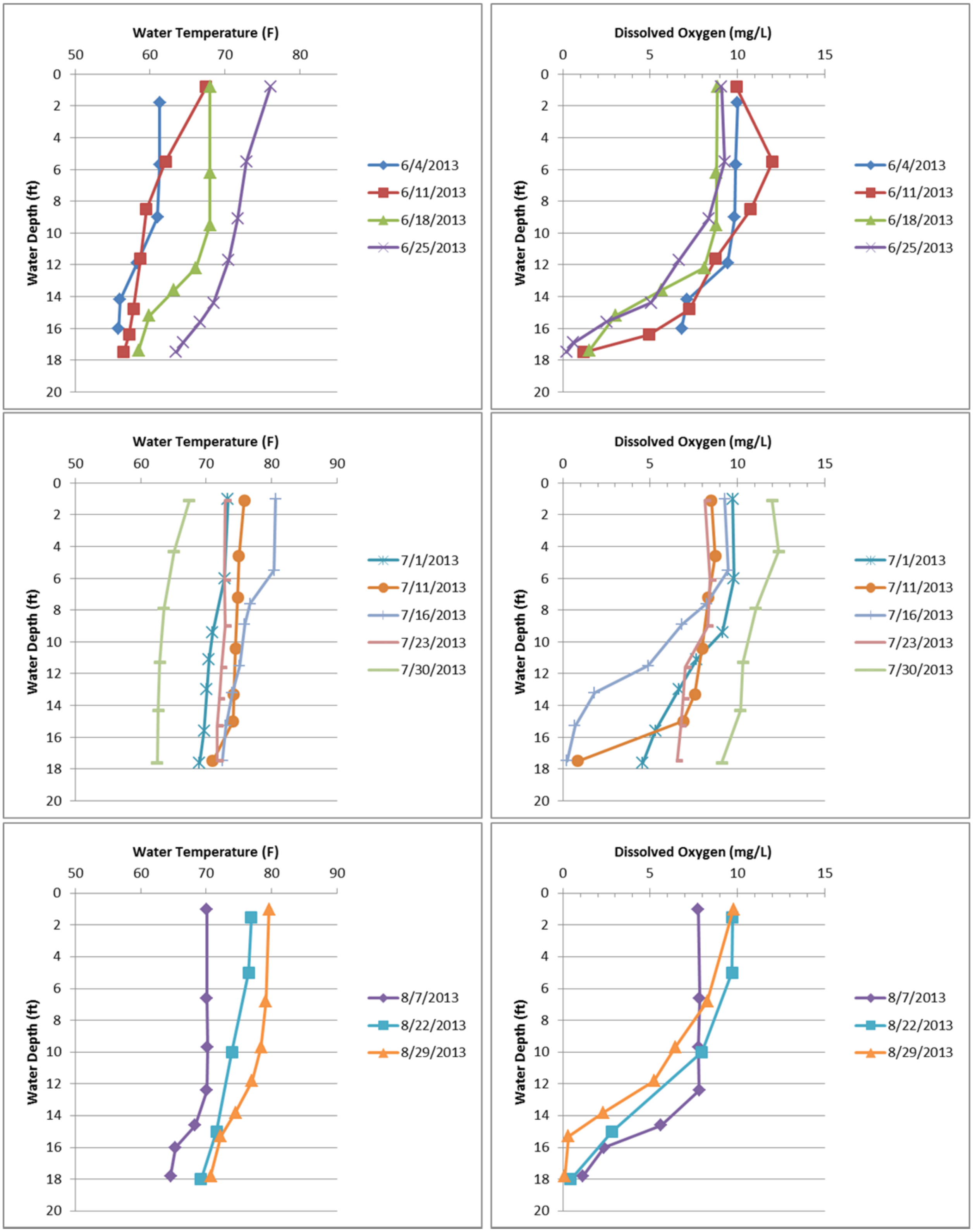

Figure 8. Temperature and dissolved oxygen profiles in Musky Bay (station MB1), June through August 2013.

Muskellunge spawn in the spring when water temperatures reach 48 to 59 degrees and may sometimes spawn again approximately two weeks later (Pratt, personal communication, 2014). As previously mentioned, a dissolved oxygen concentration of 2 mg/L at the sediment surface is required for egg survival (Pratt, 2013). Based on the 2013 monitoring data, dissolved oxygen conditions in the bottom waters of Musky Bay were already below 2 mg/L on June 11 while water temperatures were still within the muskellunge spawning temperature range.

7.3 Musky Bay Mixis Classification

Temperature and dissolved oxygen profiles were collected in Musky Bay by the LCOCD on nine dates in 2013, as shown in Figure 8 by month. As indicated in Figure 8, Musky Bay stratifies and then mixes (between 6/25 & 7/1 and between 7/16 & 7/23) at least twice during the monitoring period. During stratification, hypolimnetic dissolved oxygen levels are consistently below 5 mg/L and frequently between 0 and 3 mg/L.

For its most recent assessment, WDNR classified Musky Bay as a shallow lake. This is presumably due to the automatically generated lake classification determined using the Lathrop/Lillie equation. Given a surface area of 301.8 acres and a maximum depth of 18 feet for Musky Bay, a ratio of 2.6 results. Since this value is less than 3.8, the bay would be classified as shallow (2014 WisCALM; WDNR, 2013). However, 2014 WisCALM (WDNR, 2013) states that “use of field data on depth, area, residence time, and temperature profiles to refine the model-based lake classifications is encouraged.” The evidence of stratification in Musky Bay based on 2013 monitoring data supports its classification with the rest of LCO as a deep drainage lake according to 2014 WisCALM (WDNR, 2013), which also states “stratified lakes exhibit thermal layering throughout the summer or they undergo intermittent stratification”. Regardless of the mixis classification, Musky Bay is prone to thermal and oxygen stratification periods that strongly and negatively influence habitat and biological integrity of Musky Bay and LCO in its entirety. These periods of anoxia are influenced by the degree of nutrient loading (stressor).

8
Management for Climate Change

Climate change poses very real present and future threats to LCO's cold-water fishery. According to the Wisconsin Initiative for Climate Change Impacts (WICCI, 2011), northwest Wisconsin has seen the largest gains in growing season length of approximately two to three weeks since 1950 (see Figure 9); the largest increases in winter temperatures (up to 4.5 degrees F); and the largest increases in springtime temperatures of about 3.5 degrees F. In northern Wisconsin, mean annual air temperature is predicted to increase by 2.7 to 12.6 degrees F by 2100 (IPCC 2013; Palmer et al. 2014).

The WICCI report also concluded that since 1950 to 2006, northwest Wisconsin had increasing dry periods along with an increase in the number of intense precipitation events. The new National Oceanic and Atmospheric Administration (NOAA) Atlas 14 for Wisconsin (NOAA, 2013) estimated that the 24-hour storm with annual to 100 year recurrences ranged from 2.12 inches to 6.74 inches The magnitude of back-to-back storms occurring over two to ten day periods ranged from 2.8 to 4.5 inches (annually) to 4.56 to 6.73 inches (every 10 years). Hence, the wet periods can be expected to produce substantial runoff to LCO.

Recent research on predicted impacts to cold-water lakes in Wisconsin and Minnesota is described below.

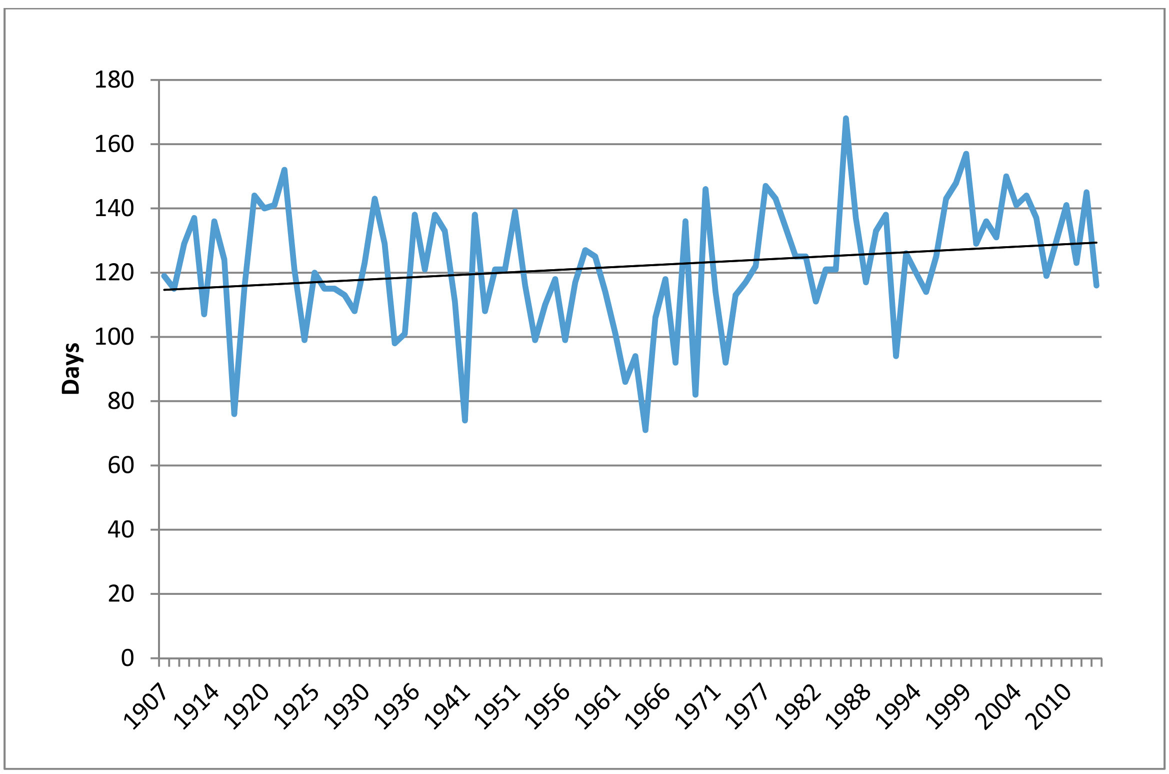

Figure 9. Growing season length for Spooner, Wisconsin (USC00478027)

8.1 Climate Change Effects on Hypolimnetic Dissolved Oxygen

Increased air and surface water temperature can lead to an earlier onset of stratification, which lengthens the summer stratification period (Sharma et al., 2011; Palmer et al., 2014). Additionally, increased average fall air temperature can delay turnover events. In Lake Mendota (Madison, Wisconsin), one study predicted that a 3-6°C increase in average fall air temperature would likely delay fall turnover by 5-10 days (Robertson and Ragotzke, 1990; Palmer et al., 2014). Under these conditions, a more stable thermocline and shallower mixed layer develops, resulting in prolonged periods of hypoxic or anoxia conditions in the hypolimnion (Palmer et al., 2014).

In LCO, low hypolimnetic dissolved oxygen (≤ 6 mg/L) has been measured on multiple occasions in Musky Bay, Stuckey Bay, West Basin, Central Basin, East Basin and the Northeast Basin (2002-2013). Elevated total phosphorus in Musky Bay has contributed to nuisance algal growth leading to loss of beneficial use and listing on the 2012 303 (d) impaired waters list. Progression to eutrophication through elevated total phosphorus inputs can be expected in this mesotrophic system, which would exacerbate current hypolimnetic dissolved oxygen conditions and likely amplify the complex effects of climate change in LCO.

8.2 Predicted Effects on Cisco Populations

Late summer conditions can be particularly critical for cold-water fisheries. As surface waters warm and hypolimnetic dissolved oxygen decreases, suitable habitat for cold-water fishes like cisco become limiting (Fang et al., 2010). These conditions can lead to summertime fish kills and decreased growth rates for cisco (Sharma et al. 2011). Cisco has been studied as a sentinel of climate change and is a species of concern in Wisconsin (Sharma et al., 2011). A 5°C increase in mean annual air temperature in Wisconsin is projected to reduce cisco populations by as much as 50%. Loss of habitat through warmer waters and lower dissolved oxygen has resulted in declining cisco populations in several northern Wisconsin lakes (Sharma et al., 2011). Furthermore, increased rates of organic matter deposition driven by eutrophication can be devastating to cold-water fisheries that depend on cold, well-oxygenated hypolimnetic waters for refugia during summer stratification (Jacobson et al. 2010).

If cold-water fisheries are managed without consideration of these issues, many cisco populations in this region may face extirpation by 2100 as a result of ongoing climate change (Sharma et al., 2011). As discussed in Section 5.2, whitefish are even more sensitive to changes temperature and dissolved oxygen conditions than cisco, as they prefer the bottommost waters. Climate change impacts to whitefish would therefore be greater than those predicted for cisco. As lake productivity is influenced by nutrient inputs from the surrounding landscape, management actions to reduce excessive nutrient inputs to cold-water fisheries may limit degradation of suitable habitat for sensitive species.

9
Proposed SSC

A value of **10 µg/L** is being proposed as the site-specific total phosphorus criterion for LCO in order to restore and protect designated uses and as to guide antidegradation policies. This value must be applied to LCO in its entirety, including all of its natural basins and bays, which are one integrated aquatic system

This SSC for LCO in its entirety is proposed based on the following:

1. Following commonly accepted limnological practice and terminology, the three bays (Musky, Stuckey, and Northeast) and three basins (West, Central, and East) comprise one lake referred to as Lac Courte Oreilles and are identified by one lake identification number (ID # 2390800);
2. All of the bays and basins are inter-connected and share one water level (relative to sea level except for short-term variations caused by wind, seiche, storm inflows etc.);
3. Documented impairments in Musky Bay even while the bay was meeting its WDNR-applied 40 µg/L total phosphorus criterion;
4. The direct connection of Musky Bay to LCO and, therefore, its influence on water quality in the rest of LCO;
5. Stratification status of Musky Bay as "deep" based on temperature profiles collected in the bay;
6. Evidence of significant increases in phosphorus loading to LCO since pre-settlement conditions based on the sediment diatom record;
7. Despite attainment of current total phosphorus criteria (15 µg/L) in LCO, a biologic impairment exists in the lake due to dissolved oxygen concentrations below 6 mg/L in the hypolimnion, indicating negative impacts to the cold water fishery in LCO;
8. Dissolved oxygen levels in the flocculent sediment at the bottom of Musky Bay are below concentrations necessary for muskellunge egg survival during spawning season; and,
9. The need to proactively protect against future degradation of fish populations due to climate change through watershed management practices.

Based on a review of available scientific literature, 10 µg/L was selected for LCO as appropriate for protection of water quality and the cold water fishery. A thorough review of phosphorus, dissolved oxygen, secchi depth, and chlorophyll *a* levels and health of various cold and warm-water fish species in Minnesota lakes can be found in Heiskary and Wilson (2005) and Heiskary and Wilson (2008). The important findings from these studies that support the proposed 10 µg/L total phosphorus criterion for LCO are:

- Dissolved oxygen depletion occurs when total phosphorus concentrations are greater than 10 µg/L, which is often used as an upper bound for oligotrophic conditions. A study of phosphorus and hypolimnetic oxygen demand lakes in British Columbia found that cold-water salmonid fisheries were protected with total phosphorus levels ranging from 5 to 15 ug/L (Nordin 1986).

- Whitefish and cisco are most abundant in a trophic state index (TSI) range of 30 to 40, which corresponds to total phosphorus levels of 6 to 12 µg/L.
- Typical concentrations of total phosphorus in Minnesota designated lake trout lakes is 9 to 16 µg/L. For the lakes exhibiting adequate refuge for lake trout, the summer average total phosphorus commonly ranged from 8 to 10 µg/L;
- The upper bound for total phosphorus concentrations sustaining lake trout is likely 15 µg/L.

Ultimately, phosphorus loading to LCO must be reduced to restore the water quality and biologic conditions in this unique ORW. The threat of negative impacts from climate change heightens this need.

Hydrodynamic modeling of mixing between LCO bays and basins and empirical modeling of hypolimnetic dissolved oxygen demand to support the proposed total phosphorus criterion for LCO are presented in Section 10.

10 Modeling to Support Proposed SSC

This section describes modeling approaches to support the proposed total phosphorus SSC for LCO of 10 µg/L. First, the approach used to assess improved biologic condition, as represented by hypolimnetic dissolved oxygen, is discussed. Second, the hydrodynamic model developed to predict the rate of mixing between the bays and basins of LCO is presented.

10.1 Assessment of Improved Biologic Condition

Based on the data presented in Section 7.2, the biologic condition of LCO is impaired due to hypolimnetic dissolved oxygen concentrations below 6 mg/L. Whitefish, which were shown in Section 5.2 to be the most sensitive cold-water species present in LCO, prefer to use the bottom waters of a lake. Therefore, an important aspect of evaluating biologic conditions in LCO relates to reductions in hypolimnetic oxygen demand with lower total phosphorus (TP) concentrations.

Chapra and Canale (1991) showed that hypolimnetic oxygen demand (HOD) varied across lakes as a function of $TP^{0.478}$. The following equation can be used to project HOD based on observed depletion rates and baseline and future TP concentrations:

$$HOD_{future} = HOD_{present} * (TP_{future}/TP_{present})^{0.478}$$

Where,

HOD_{future} = projected hypolimnetic oxygen demand, mg/L/d

$HOD_{present}$ = current hypolimnetic oxygen demand, mg/L/d

TP_{future} = desired future water column total phosphorus, µg/L

$TP_{present}$ = current water column total phosphorus, µg/L

As described in Section 7.2, profiles of temperature and dissolved oxygen were collected at seven LCO stations in 2013 (LCO 1 thru 6 and MB1; Figure 2). The profiles were inspected to identify measurements in the bottom waters of the hypolimnion where oxygen was clearly depleted, and average dissolved oxygen concentrations were calculated at these locations for each date and station. Rates of hypolimnetic oxygen demand were then determined using linear regression on the time series. R-squared values were high for each bay and basin and ranged from 0.83 to 0.99.

Using the equation above, the calculated current hypolimnetic dissolved oxygen rates, and current water column total phosphorus concentrations (as represented by seasonal means for the 2002 to 2013 period), future hypolimnetic oxygen demand was predicted for each bay and basin with a future condition of 10 µg/L total phosphorus in the water column. The percent decrease in future hypolimnetic oxygen demand was then calculated for each bay and basin.

As shown in Table 6, improvements in hypolimnetic oxygen demand are most striking in Musky Bay, where HOD is nearly cut in half.

Table 6. Present and future total phosphorus and hypolimnetic dissolved oxygen demand in LCO basins and bays.

Bay/Basin	$TP_{present}$ (µg/L)	$HOD_{present}$ (mg/L/d)	TP_{future} (µg/L)	HOD_{future} (mg/L/d)	Decrease in HOD (%)
Musky Bay	37.1	0.282	10	0.151	47%
Stuckey Bay	15.7	0.103	10	0.083	19%
West Basin	13.2	0.148	10	0.130	12%
Central Basin	9.8	0.114	10	0.115	-1%
East Basin	11	0.123	10	0.118	4%
Northeast Bay	10.9	0.07	10	0.067	4%

10.2 Hydrodynamic Modeling

A fine-scale hydrodynamic model of LCO was developed to directly predict the amount of mixing between bays and basins in support of the proposed SSC.

The hydrodynamic model was based upon the Environmental Fluid Dynamics Code (EFDC), a U.S. Environmental Protection Agency (EPA)-supported modeling framework. Application of the EFDC model consisted of the following steps:

- Development of a model grid
- Comparison of model predictions to surface temperature data
- Application of the model to define mixing between bays and basins

Development of the model grid consisted of digitizing the bathymetric map of LCO, then developing a curvilinear segmentation scheme that captured the variation of the bathymetry. The resulting grid has 2,125 cells horizontally; when applied in three-dimensional mode there are a total of 21,250 cells.

Once the model grid was established, EFDC was applied using observed 2012 climatic data (from Sawyer County Airport and the Rice Lake solar radiation site) as model inputs. Surface temperatures predicted by EFDC were successfully compared to observed data from multiple lake stations to demonstrate the reliability of model predictions.

The next step of EFDC application consisted of a dye tracer simulation to define mixing between bays and basins. The model was vertically condensed into two dimensions for computational purposes, and a slug of conservative dye (100 mg/L; ~500 million grams total) was entered into the model at Musky Bay on June 1. EFDC predicted the rate at which this dye spread throughout the rest of the lake over the remainder of the year. The volumes of Musky Bay and West basin are 4.9 and 39 million cubic meters, respectively.

Results from the dye simulation are provided in Figure 10, where predicted dye concentrations are given in two-week intervals. As seen in Figure 10, the concentration of the dye slug moving through West basin is between 11 and 22 mg/L after 10 weeks after dye release from Musky Bay.

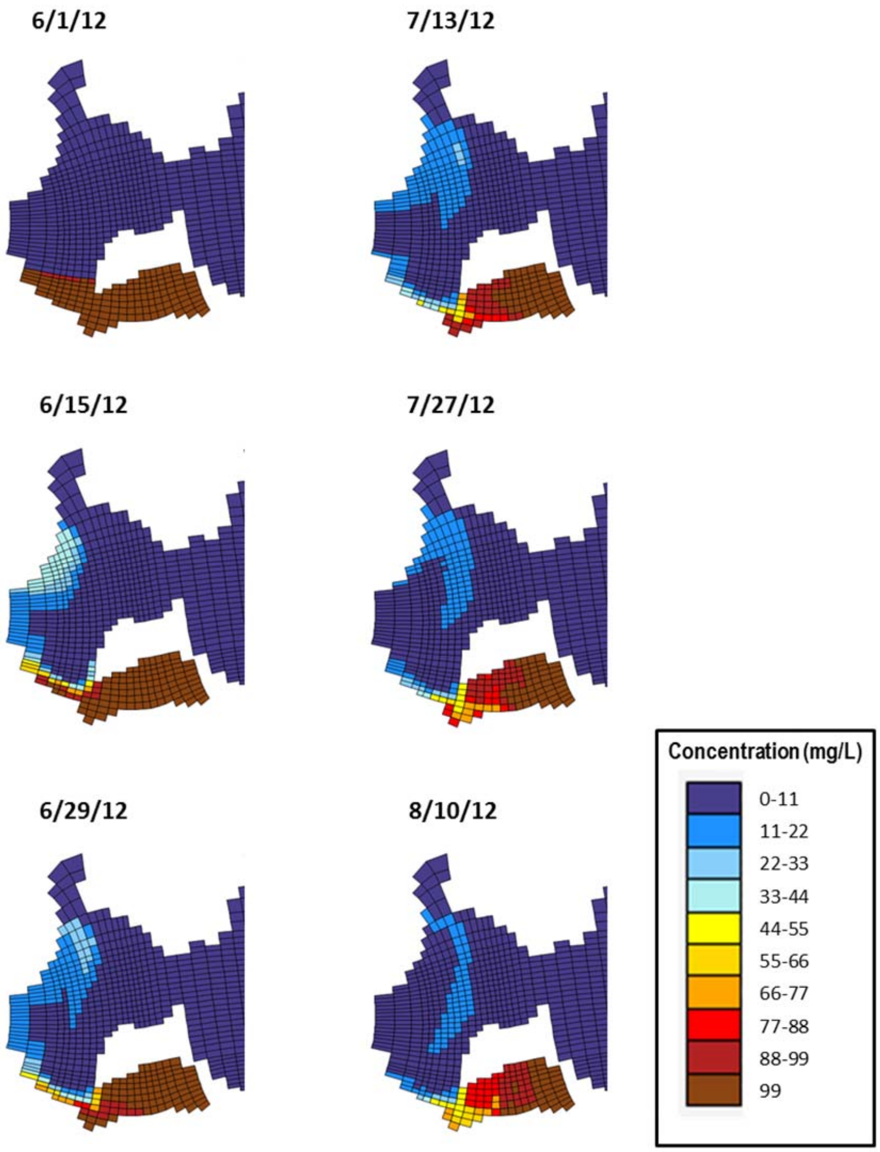

Figure 10. Predicted dye concentrations in LCO at two-week intervals following release of 100 mg/L in Musky Bay on June 1.

Figure 11 shows the time series of the predicted mass of the dye slug in Musky Bay and West basin as the percent of the mass of dye released. After one month, 38% of the dye slug has moved into West basin from Musky Bay. After two months, almost half (48%) of the dye mass has moved into West basin.

The hydrodynamic model clearly shows the influence of loads entering Musky Bay on West basin, and results support consideration of LCO as one integrated aquatic system.

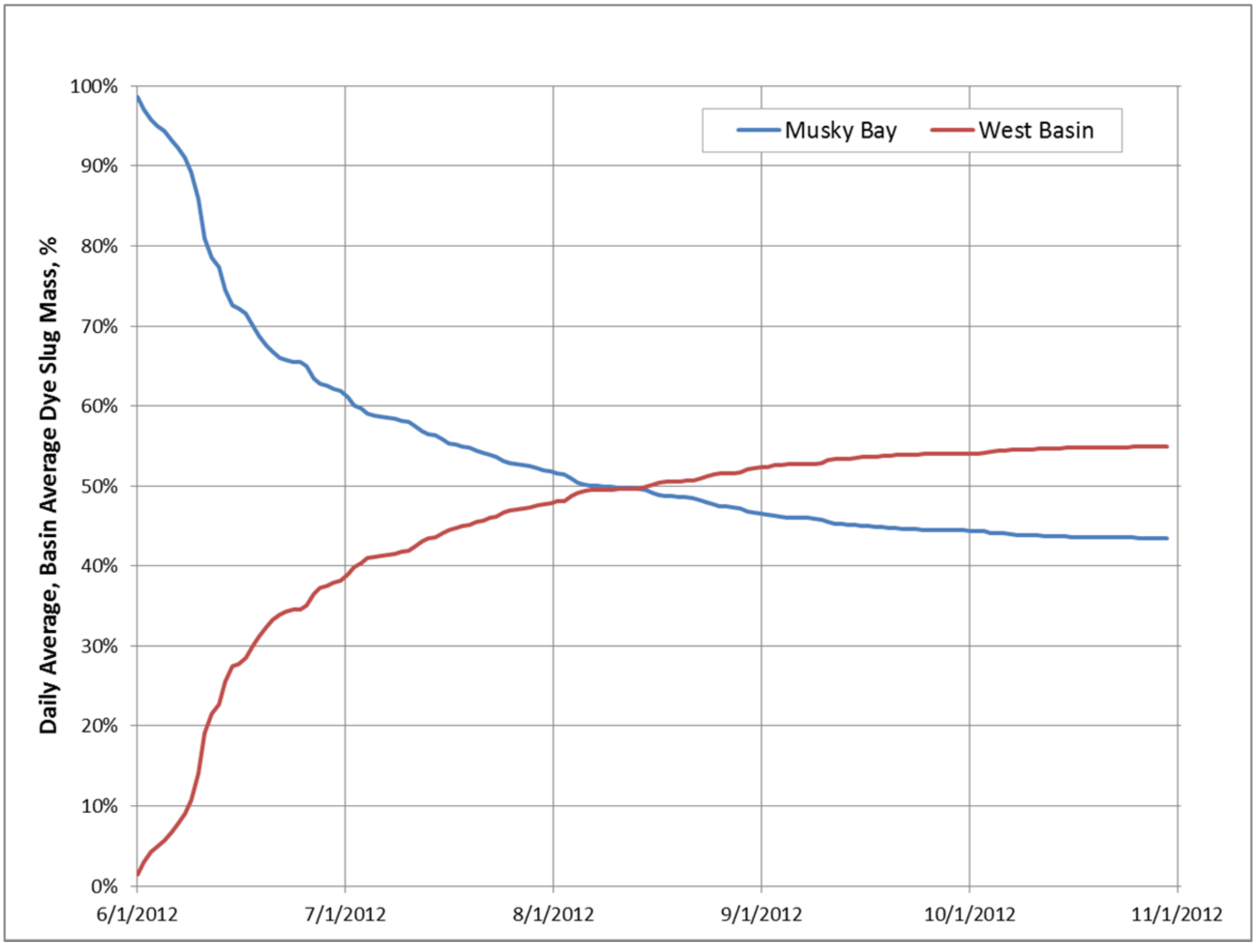

Figure 11. Predicted daily average mass of dye slug in Musky Bay and West basin (percent). Dye was released in Musky Bay at 100 mg/L on June 1.

11
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